## CLAIM + DETAILED DESCRIPTION

[Claim(s)]
[Claim 1]Have 2 value structures on the surface of a substrate, and a distribution state of said 2 value structures is changed, An optical element, wherein it is an optical element to which an effectual refractive index of said substrate is changed with the position in said surface, and a wave face of incidence light is changed and a size of one way of said surface of 1 set of 2 value structures of said 2 value structures is the detailed structure below a wavelength of said incidence light.
[Claim 2]A field where a value of said effectual refractive index for giving a function as an optical element changes gently from the maximum to the minimum exists in said surface along with the two or more same direction, The optical element according to claim 1, wherein a periodic repetition of detailed structure below a wavelength of said incidence light for control of said effectual refractive index is incorporated into each of that field and pattern distribution of said detailed structure has change in a periodic repetition of said detailed structure.
[Claim 3]The optical element according to claim 2, wherein the direction of change of pattern distribution of said detailed structure is one dimension.
[Claim 4]The optical element according to claim 3, wherein said effectual direction of a repetition of change of a refractive index and the direction of change of pattern distribution of said detailed structure are parallel.
[Claim 5]The optical element according to claim 3, wherein said effectual direction of a repetition of change of a refractive index and the direction of change of pattern distribution of said detailed structure are perpendicular.
[Claim 6]The optical element according to claim 2, wherein the directions of change of pattern distribution of said detailed structure are two dimensions.
[Claim 7]The optical element according to claim 1, 2, 3, 4, 5, or 6, wherein said 2 value structures are formed by etching of said surface.
[Claim 8]The optical element according to claim 1, 2, 3, 4, 5, or 6, wherein said 2 value structures are formed of a thin film provided on said surface.

[Detailed Description of the Invention]
[0001]
[Field of the Invention]Optical connection, optical communications, etc. between the boards which this

invention required for the design of the micro-optics element, for example, carry two or more chips between the chips of LSI or between ** equipped with a board, and between devices are related with the micro-optics element covering all the fields using a lightwave signal.
[0002]
[Description of the Prior Art]Drawing 7 is a figure for explaining the conventional optical element.
[0003][ a micro-optics element ] [ refracted type optical elements, such as the lens 71 as shown in drawing 7 (a), ] It is ideal that the greatest thickness as removed a part for the thickness which is equivalent to the **** difference of the integral multiple of the wavelength of the light to be used from the Reasons of thickness becoming thick too much and shown in drawing 7 (b) uses phase Fresnel's lens 72 equivalent to a part for one wave of **** difference.
[0004]The position of each belt of Fresnel's lens is denoted by a following formula, when distance from the center is set to r.
[0005]r=(2nflambda10$n^2$lambda$^2$) $^{1/2}$ -- (1)
Here, lambda shows which belts the focal length of a lens and n are positive integers, and the wavelength of light and f are from the center. Fresnel's lens is a condensing element which the effect of diffraction contributes greatly and changes a wave face in refraction and the outside number field of high frequency in the inside number field of low frequency waves. If the shape as a design is reproducible, the efficiency near about 100% will be acquired, but. It is difficult to reproduce faithfully a continuous curved surface like Fresnel's lens 72 of drawing 7 (b), the slope where inclinations differ, etc., and if integration of the element from which a focal length, the diameter of a lens, etc. differ is considered while the miniaturization of an element and a miniaturization progress, it is almost impossible practical.
[0006]On the other hand, the phase type Fresnel zone plate (FZP) 73 shown in drawing 7 (c) is an element which performs wave face conversion only by the diffraction effect, and it is possible that Fresnel's lens 72 of (b) was approximated by the phase of 0 and two values of pi. In this element, since the depth should just form a fixed slot as shown in (c), a miniaturization and also when it is integrated, if the process art in the large scale integration circuit (LSI) of the conventional semiconductor and a lithography technology are used, it can manufacture comparatively easily. However, since there are few diffraction effects, even when it is able to form as a design, 40.5% and efficiency are low in especially the central part.
[0007]Then, in order to make an element with higher efficiency using the lithography technology of LSI, the digital blazed element 74 which shows the ideal shape of (b) to drawing 7 (d) approximated in stairs type shape came to be made.
[0008]Since it is easy, drawing 7 (d) illustrates the case of four-step approximation. In fact, eight steps, 16 etc. steps, etc. are made as an experiment. These elements form the approximation shape of a $2^n$ stage by repeating the resist pattern formation by exposure, and the etching process which made it the mask n times. Theoretical diffraction efficiency improves with 81%, 95%, and 99% as it goes up with four steps, eight steps, and 16 steps, but the part, and the number of masks and the number of processes to need also increase with 2 times, 3 times, and 4 times, mask accuracy and the accuracy of superposition are also required in connection with it, and the rise of cost is not avoided.
[0009]The element which adjusts the phase contrast for functioning effectively as an optical element so far by changing thickness was described. However, since phase contrast is decided by the thickness and the refractive index of an element, thickness is set constant, and the method of adjusting phase contrast by changing a refractive index is also considered.

[0010]It is changing the refractive index of an element medium, and the refractive-index change element 75 that a **** difference will be modulated is shown, drawing 7 (e) shows the thickness and, as for drawing 7 (e) and (f), drawing 7 (f) shows the refractive index.

[0011]If such an element can be realized as a design, it will be thought that efficiency reaches to 100%. For example, changing the refractive index of an element medium is performed by the ionic exchange method etc. which are diffused alternatively. It is possible to change refractive-index distribution from the central part uniformly toward a circumference part by this method, and to form a simple circular lens element in a substrate face. However, since it is difficult to control the slope of refractive-index distribution by a place arbitrarily, it is impossible to integrate and form the lens element corresponding to various demands or to realize local refractive-index distribution as shown in drawing 7 (f).

[0012]

[Problem to be solved by the invention]As mentioned above, that from which a phase changes continuously in the conventional phase type optical element as stated is difficult to manufacture. When reducing the number of levels of the phase, efficiency became low, when increasing the number of levels, the number of manufacture processes of that from which a phase changes to many values gradually increased, cost went up, and there was a problem that manufacture became difficult.

[0013]This invention was originated in view of the above-mentioned problem, and the purpose has few manufacture processes, is comparatively easy to manufacture, and there is in obtaining the high optical element of diffraction efficiency which can be integrated.

[0014]

[Means for solving problem]In order to solve said technical problem, in this invention, the phase of the light penetrated or reflected is controlled by 2 value structures with a cycle shorter than the wavelength of the light to be used, and an optical element is formed.

[0015]Namely, the optical element of this invention has 2 value structures on the surface of a substrate, and changes the distribution state of said 2 value structures, It is an optical element to which the effectual refractive index of said substrate is changed with the position in said surface, and the wave face of incidence light is changed, and said 2 value structures are characterized by the size of one way of said surface of 1 set of 2 value structures being the detailed structure below the wavelength of said incidence light.

[0016]The field where the value of said effectual refractive index for giving the function as an optical element changes gently from the maximum to the minimum exists in said surface along with the two or more same direction, A periodic repetition of the detailed structure below the wavelength of said incidence light for control of said effectual refractive index is incorporated into each of that field, and pattern distribution of said detailed structure has change in a periodic repetition of said detailed structure.

[0017]It is characterized by the direction of change of pattern distribution of said detailed structure being one dimension.

[0018]It is characterized by said effectual direction of a repetition of change of a refractive index and the direction of change of pattern distribution of said detailed structure being parallel.

[0019]It is characterized by said effectual direction of a repetition of change of a refractive index and the direction of change of pattern distribution of said detailed structure being perpendicular.

[0020]It is characterized by the directions of change of pattern distribution of said detailed structure being two dimensions.

[0021]Said 2 value structures are formed by etching of said surface.

[0022]Said 2 value structures are formed of the thin film provided on said surface.
[0023]In this invention, since refractive-index control by ionic exchange, thermal diffusion, etc. is not performed and middle thickness is not needed according to the above-mentioned structure, either, the detailed high optical element of diffraction efficiency can be produced comparatively easily using the method of the usual lithography. Integration is also possible.
[0024]
[Mode for carrying out the invention]Hereafter, an embodiment of the invention is described in detail using Drawings. With the Drawings explained below, what has the same function attaches the same numerals, and explanation of the repetition is omitted.
[0025]Drawing 1 is a figure showing the concept of the optical element formation by the artificial refractive-index control structure (ARI structure) used as the fundamental view of this invention.
[0026]If the light 2 generally enters into the penetrated type diffraction grating 10, the diffraction light 3 will be emitted in the direction of the difference angle theta from an incidence direction.
[0027]At this time, the angle of diffraction theta uses the wavelength lambda of light, and the cycle p of a lattice, and is sin theta=m lambda/p. -- It is expressed with (2). m is a degree of diffraction and the primary diffraction light in m= 1 spreads it to the smallest angular orientation.
[0028]However, the angle theta of primary diffraction light becomes large, so that the cycle p of a lattice becomes short, as shown also in a formula (2).
[0029]If the cycle p becomes short from the wavelength lambda of incidence light as shown in drawing 1 (b), it will be set to sintheta>1 and the primary diffraction light 3 will disappear. If the primary diffraction light 3 is lost, the light which passes this diffraction grating 1 will turn into only the zero order light 4.
[0030]Compared with the wavelength lambda of incidence light, the zero order light 4 which the cycle p of the lattice served this diffraction grating 1 like a homogeneous medium when short enough, and penetrated the diffraction grating 1 receives the phase modulation same with having penetrated the medium of the refractive index smaller (close to the refractive index of air) than the refractive index of the substance which forms the diffraction grating 1.
[0031]That is, the diffraction grating 1 of drawing 1 (b) is served like a homogeneous medium with the mean value of refractive-index $n_m$ of a substance, and surrounding refractive-index $n_0$. Here, if the substance portion of a diffraction grating will be called a pattern section, the refractive index on appearance is controllable by changing the pattern density of a lattice. An optical element can be made from changing an effectual refractive index by a place using this character.
[0032]A refractive index is not directly changed by changing composition of substances, such as ionic exchange, for refractive-index distribution as shown in drawing 7 (f), as conventional technology explained by the way, An effectual refractive index is changed, for example, effective-index distribution equivalent to drawing 7 (f) is given, and the wave face can be turned in the specific direction, or it can be made to condense by changing the phase of penetration light (or reflected light) by the phase grating of two values with a cycle shorter than the wavelength of the light to be used. Drawing 1 (c) is a figure showing the example which forms an optical element by changing pattern density to drawing 1 (a) and (b) using the shown artificial refractive-index control structure.
[0033]Namely, the optical element of this invention has 2 value structures on the surface of a substrate, and changes the distribution state of 2 value structures, It is an optical element to which the effectual refractive index of a substrate is changed and the wave face of incidence light is changed, and the size of one way of

the direction of the surface of 2 value structures of 1 set of convexes and ** of 2 value structures is the detailed structure below the wavelength of incidence light.

[0034]What is equivalent to the usual diffraction grating as a kind of optical element, and the thing equivalent to a prism, Most elements producible by other methods, such as an element to which the direction of movement of lights, such as a thing equivalent to Fresnel's lens, is changed, an element which branches light in the direction of plurality, and a condensing element, are altogether realizable by the effective-index control structure (artificial refractive-index control structure) by this invention.

[0035]Formation of a pattern section is realizable with the lithography used when producing integrated large-scale electric circuits, such as LSI, and the art of etching. For example, in the above-mentioned formula (2), when trying to make the optical element to light with a wavelength of 1.55 micrometers used for optical communications, since the cycle p is 1.55 micrometers which is in agreement with the wavelength lambda, that primary diffraction light disappears makes the cycle p smaller than this. As for the cycle p, in order to obtain the more stable refractive-index control structure although 1.54 micrometers of the cycle p may be sufficient since the maximum of the cycle p is 1.55 micrometers, it is desirable that it is smaller than one half of wavelengths. Therefore, as for the cycle p, 0.775 micrometer or less is desirable. If a concrete numerical value is mentioned, the pattern section for phase control will be changed in 0.05 micrometer - 0.65 micrometer by a place as a cycle of p= 0.7 micrometer to the wavelength of lambda= 1.55 micrometers. Here, with the lithography for the present LSI manufacture, since a pattern still more detailed than 0.1 micrometer could be formed by X ray exposure, an electron-beam-exposure method, etc., the detailed pattern which can be formed with lithography was considered as 0.05 micrometer. As long as it can form a detailed pattern, the pattern section of the periodic structure for artificial refractive-index control with a cycle of 0.7 micrometer may be changed in 0.01 micrometer - 0.69 micrometer, etc. broadly as much as possible.

[0036]Two value structures are formed by the thin film which was formed in one on the surface of the substrate by etching etc., or was provided in the substrate face. In the work example and figure which are shown below, the member which forms a substrate and a pattern section can apply an ordinary glass material, quartz ($SiO_2$), GaAs, etc., for example. When using visible light light sources, such as HeNe laser (wavelength of 632.8 nm), materials, such as glass, quartz, SiC, and GaN, are suitable from the field of transmissivity. A surface emission-type laser etc. can apply SiC, SiN, GaAs, GaN, etc. other than glass and quartz as a transparent member to such lights to the light of the range whose wavelength is 800-1000 nm too. In addition to an above-mentioned material, Si, InP, etc. can be used in the wavelength bands (the communication wavelength of 1.3 micrometers, 1.55 micrometers, etc.) over 1 micrometer by the side of long wavelength. Although the example of a concrete material was shown above, the member which serves as a substrate in fact is [ anything ] good if a part also penetrates the light of the wavelength to enter in a penetration optical system, and since the coat of the reflection film can be carried out to the surface later, the quality of the material is not chosen in a catoptric system. In order to carve the above-mentioned substrate and to form it, the same quality of the material as a board part may be sufficient as the pattern section (lattice part) for artificial refractive-index control structure, and in order to form by the method of sticking other quality of the materials on a board part, or applying to it, the different quality of the material from a board part is also available for it.

[0037]If explanation is filled up about the formation method of a pattern section, etching, the exposure development of sensitization material, a mold (model aggressiveness), etc. will be mentioned. [ as a material in the case of sticking, applying and forming ] Polyimide, such as fluorinated polyimide, BCB (benz-cyclo-

butene: photosensitive ****), Polymer, such as a resist acrylic resins, such as a photo-setting resin, UV epoxy resin, and PMMA (usable [ as those with sensitivity and a resist ] to ultraviolet rays and an electron beam), at large, is mentioned, and SOG (spin ON glass) etc. are mentioned as glass material which can be applied.
[0038]
[Working example]A concrete example is given below and the optical element by this artificial refractive-index control structure is explained.
[0039]Two language "element cycle direction" and the "structure cycle direction" which are used below are explained.
[0040]The "element cycle directions" is the direction of a refractive index gradient which carries out phase modulation, i.e., the direction, and the repetition direction of change of an effectual refractive index, in order to give the function as an optical element. When phase modulation, such as a one-dimensional diffraction grating (grating), is periodic, the word element cycle "direction" is applied, but this language will be used for convenience also about the case where phase modulation is not periodic, like Fresnel's lens.
[0041]The "structure cycle directions" is the periodic direction of the detailed structure for refractive-index control, i.e., the pattern division direction, and the direction of change of pattern distribution of detailed structure.
[0042]Work example 1 (one-dimensional diffraction grating: parallel ARI structure)
The example which is in agreement in the element cycle direction (the direction of a refractive index gradient) for optical element formation of the structure cycle direction of artificial refractive-index control is shown in drawing 2. Drawing 2 (a) and (b) is two examples which formed the one-dimensional regular-intervals diffraction grating (grating) without a lens function by artificial refractive-index control structure, respectively, and its element cycle is constant. 5 is a one-dimensional diffraction grating and 6 is a substrate. The figure where (a) and (b) looked at a part of element from the top, and (c) are the sectional views of (a).
[0043]The refractive index gradient or phase contrast slope in the cycle of one element, [ a linear diffraction grating ] Drawing 2 (a), [ forming the line pattern of line width which gives the phase contrast which divides the inside of the cycle of one element into the artificial refractive-index control structure cycle below a wavelength, and is demanded one by one in each divided structure cycle, as shown in - (c) ] The phase diffraction grating 7 as shows drawing 2 (d) the sectional view, and an optical element with an equivalent function are made.
[0044]Drawing 2 (a) and the difference in (b) are as follows. Since the rule of touching an end with the certainly larger phase contrast in a structure cycle in the line pattern within 1 structure cycle was established and the line pattern is arranged, if the phase contrast which should be given is decided by (a), there will be no other flexibility and line pattern arrangement will be uniquely decided by it. On the other hand, in (b), since a rule as shown in (a) was not established but it left the locating position of the line pattern within 1 structure cycle as flexibility, a locating position which makes diffraction efficiency as an optical element the maximum, for example can be optimized.
[0045](One-dimensional lens: Parallel ARI structure) Again, [ in addition, an optical element which is equivalent to the one-dimensional lens (or cylindrical lens) which had a condensing function only in the one direction with the one-dimensional element in rectangular coordinates ] The example which the structure cycle direction of the above artificial refractive-index control forms with the structure which is in agreement in the element cycle direction is considered the same way.
[0046]Although not shown in a figure, in drawing 2 (a) and (b), each element cycle is not constant, it is

considered as the macro structure where the coordinate value of the corner point of the one direction of rectangular coordinates is given by an above-mentioned formula (1), and the example made into drawing 2 (a) and (b) and the same ARI structure is also considered in each of that belt so that it may have a condensing function.

[0047]A work example 2 (Fresnel's lens: parallel ARI structure)

Other examples which are in agreement in the element cycle direction (the direction of a refractive index gradient) for optical element formation of the structure cycle direction of artificial refractive-index control are shown in drawing 3.

[0048]Drawing 3 (a) is the example which formed Fresnel's lens with a condensing function by artificial refractive-index control structure. 8 is Fresnel's lens.

[0049]Such an optical element can be considered to be a one-dimensional element in polar coordinates in which a coordinate system differs from a case (rectangular coordinates) of drawing 2.

[0050]A cycle in this optical element is not constant, and a position of a corner point of that ring belt is decided by an above-mentioned formula (1).

[0051]In this work example, since the direction of a refractive index gradient is ********, the direction of a structure cycle of artificial refractive-index control also turns into ********, [ forming a circumference pattern of line width which gives phase contrast which divides inside of a cycle of one element into a cycle below a wavelength at ********, and is demanded one by one in each divided structure cycle ] A figure seen from a top to drawing 3 (b) and an optical element with a function equivalent to usual Fresnel's lens 9 which controlled a phase by thickness as shows the sectional view at (c) are made. A shade in drawing 3 (b) expresses size of thickness of Fresnel's lens 9.

[0052]Here, in order to avoid the complexity of a figure, and duplication, established the rule of touching an end with the certainly larger phase contrast in 1 structure cycle in the circumference pattern within 1 structure cycle, and gave only the example which has arranged the circumference pattern, but. The element which it leaves as flexibility without deciding it whether a circumference pattern is arranged beforehand to be which portion in 1 structure cycle like the case of the work example 1 is also considered.

[0053]It cannot be overemphasized that it may have further a repetition of the same circumference pattern also as the outside of the structure shown in drawing 3 (a).

[0054]Work example 3 (one-dimensional diffraction grating: rectangular cross ARI)

Next, the example of an element which intersects perpendicularly with the element cycle direction (the direction of a refractive index gradient) for optical element formation of the structure cycle direction of artificial refractive-index control is shown in drawing 4.

[0055]Drawing 4 (a) is an upper surface figure showing the example which realized the same regular-intervals diffraction grating as drawing 2 by artificial refractive-index control structure. 11 is a one-dimensional diffraction grating.

[0056]In this case, since the cycle of artificial refractive-index control structure is perpendicularly set up to the direction of a refractive index gradient, all the refractive index gradients in each structure cycle become a form where the refractive index gradient in an element cycle was changed into the rate of a pattern as it was as [ it is equal and ] shown in a figure.

[0057]Drawing 4 (b) is an enlarged drawing of the pattern 12 within a round term of (a), and imposes the arrangement rule of arranging a pattern from which or the decided end.

[0058]Although drawing 4 (C) is similarly an enlarged drawing of the pattern 12 for a round term, it arranges

here under the rule of bringing near a pattern by the central part. Thus, if it is the arrangement which transposed the refractive index gradient to the rate of pattern area, it does not adhere to these two kinds, but free arrangement is possible.
[0059](One-dimensional lens: Rectangular cross ARI) Again, [ in addition, an optical element which is equivalent to the one-dimensional lens (or cylindrical lens) which had a condensing function only in the one direction with the one-dimensional element in rectangular coordinates ] The example formed with the structure where the element cycle direction and the structure cycle direction of the above artificial refractive-index control cross at right angles is considered the same way. This is shown in drawing 4 (d) (upper surface figure). 13 is a one-dimensional lens. Also in this example, if the shape of the internal pattern 12 is structure as shown in drawing 4 (b) and (C), and the arrangement which transposed the refractive index gradient to the rate of pattern area also except it, it does not adhere to these two kinds, but free arrangement is possible for it.
[0060]Work example 4 (Fresnel's lens: rectangular cross ARI)
Other examples of an element which intersects perpendicularly with the element cycle direction (the direction of a refractive index gradient) for optical element formation of the structure cycle direction of artificial refractive-index control are shown in drawing 5 like the work example 3.
[0061]This work example is an example which formed Fresnel's lens with the same function as drawing 3 of the work example 2 with the structure where the element cycle direction and the ARI structure cycle direction cross at right angles. It is usual Fresnel's lens in which 14 controlled Fresnel's lens and 15 controlled the phase by thickness. An optical element with a function equivalent to the figure seen from the top to drawing 5 (b) and phase Fresnel's lens 15 as show the sectional view to (c) is made. The shade in drawing 5 (b) expresses the size of the thickness of Fresnel's lens 15.
[0062]About arrangement of an internal structure, if it is structure as shown in drawing 4 (b) and (c), and the arrangement which transposed a refractive index gradient to a rate of pattern area also at others, it does not adhere to these two kinds, but free arrangement is possible.
[0063]At drawing 3 (a), although the pattern 12 was illustrated only to the central part of Fresnel's lens 14, it cannot be overemphasized that the same pattern also as a circumference section of the outside is formed. It cannot be overemphasized that it may have further a repetition of the same pattern also as the outside of structure shown in drawing 3 (a).
[0064]A more complicated work example which is somewhat different from an old example in the 5th work example is indicated. a work example quoted so far -- the structure cycle direction (A) of artificial refractive-index control -- the element cycle direction (the direction of a refractive index gradient) (B) for optical element formation -- being in agreement (namely, parallel :A||B) -- or -- intersecting perpendicularly (A**B), although it was one of examples, In this example, it is an example which has a two-dimensional structure where the direction of A has the two directions of a direction which is in agreement in the direction of B, and a direction which intersects perpendicularly with it.
[0065]In drawing 6, in order to avoid the complexity of a figure, only the example of a one-dimensional diffraction grating is given. 16 and 17 are one-dimensional diffraction gratings, respectively. ARI structure is realizable under the same rule also to the one-dimensional lens quoted so far and Fresnel's lens (circular).
[0066]Drawing 6 (a) is the example which made arrangement flexibility of the high refractive-index material pattern within the 1 structure of artificial refractive-index control structure two flexibility, a parallel direction and the right-angled direction, and attached the priority.

Drawing 6 (b) is the example which made arrangement flexibility of the pattern 1 flexibility by considering it as a square area.

[0067]It is intelligible when explanation is filled up about the above "element cycle direction" and the "structure cycle direction", and drawing 2 (a) and drawing 4 (a) are contrasted. Both of these two Drawings are the structures for realizing the one-dimensional diffraction grating which has the same function. Although the element cycle direction of both structures is the same, the structure cycle directions differ. The direction of coincidence (parallel) and drawing 4 (a) has [ the direction of drawing 2 (a) / the element cycle direction and the structure cycle direction ] the element cycle direction and the structure cycle direction perpendicular [ that is, ].

[0068]As for this invention, although this invention was concretely explained based on the embodiment above, it is needless to say for it to be able to change variously in the range which is not limited to said embodiment and does not deviate from the gist. For example, drawing 2 (a), (b), drawing 3 (a), drawing 4 (a), (d), drawing 5 (a), and drawing 6 all [ of (a) and (b) ] illustrate a part of optical element, and it cannot be overemphasized that these repetitions follow the circumference at the lengthwise direction and the transverse direction. Two or more these patterns may be combined and may be formed.

[0069]

[Effect of the Invention]Since according to this invention refractive-index control by ionic exchange, thermal diffusion, etc. is not performed and middle thickness is not needed, either, as explained above, The detailed high optical element of diffraction efficiency can be produced comparatively easily using the method of the usual lithography, and it is effective also in it being possible to integrate this.

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[Translation done.]